Design of an ultrasound measurement system with a mode conversion for a prism technique

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Abstract:

This paper is devoted to the realization of a non-destructive measurement system based on the principle of the ultrasonic inspection (pulse echo), allowing the evaluation of elastic constants of the second order for any machined or moulded material in the form of prism. The simplicity and the reliability of the system are explained by the possibility of measuring longitudinal and transverse speeds with a relative facility. It makes it possible to examine a very great number of specimens for a short length of time with ultrasonic impulses. It could be useful for the determination of the elastic constants of the third order due to the anisotropy introduced by the external stresses such as the uniaxial stress and the hydrostatic pressure.

Compared to the theoretical values of longitudinal and transverse speeds in Aluminium, glass and mortar, the results obtained in this experience are very important.

I. Introduction

The materials have a certain resistance to the passage of the ultrasounds. This resistance known under the name of impedance is really a function of the modulus elasticity and the material density. The impedance value changes from one material to another and the difference between two materials constitutes what is called an interface.

As in optics, each time that an aural signal meets an interface, part of incidental energy is transmitted about the second medium, while the other part is reflected, while holding account that the directions of the transmission and the reflexion depend on the incidence angle and the sound wave. *[3]*

At the time of the reflexion, energy thus reflected (echo) is used to identify, locate and characterize the interface between two mediums.

In the world of the ultrasounds, the ultrasonic waves constitute an average privileged person of investigation in the study of the mechanical behaviour of materials, as well as the analysis and the characterization of the mechanical properties of these materials. *[3]*

Allowing the measurement of the elastic constants for the second and third order, the measurement techniques of ultrasonic wave’s propagation velocities knew a very significant evolution last years, and several devices of measurement were elaborate in this direction. But the majority as of these methods presents a considerable disadvantage which is the complexity of the measurement system.

2. Measurement system

2.1 Synoptic diagram

The schematic diagram of the complete measurement system is shown on figure.1. it is composed of an ultrasonic generator impulses carrying the reference (parametrics 5077PR), a transducer for immersion of 2.5 MHz (parametrics V306SU), a numerical oscilloscope (Tektronics TDS 1002), a portable computer with the Wave-star software which will allow us the acquisition of the data and posting the curves referring to the echoes and finally, of the cell with transducer. *[1]*

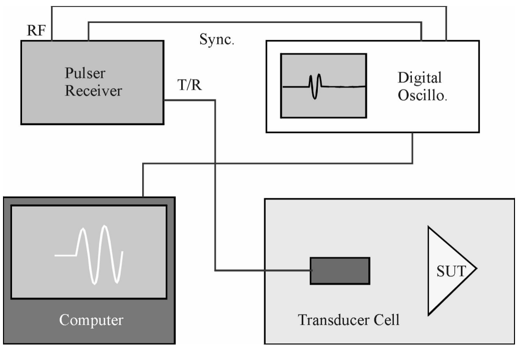

Figure1. Schematic diagram of the system measurement [1]

2.2 Experimental set up

Installed on the support carry-samples, the material in the form of prism follows the same rotation of the engine. It is very significant to announce that the choice of the direction and the swing angle is always allocated to the operator. The transducer emits a beam of ultrasonic waves which crosses the liquid then the sample to return to the source (figure2). The cylindrical sensor focused assistance to concentrate the energy of the ultrasonic waves in the center of the principal face of the prism. When the engine is in initial position; at-rest state; the major part of incidental energy is reflected towards the source, and the relative echo gives the time of transit in the liquid medium.

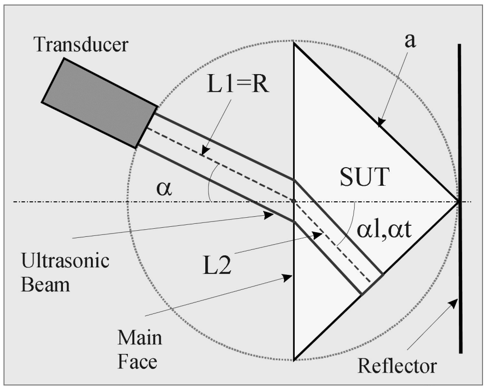

Figure2. Synoptic illustrating the technique of prism [2]

By increasing the angle of incidence slowly, the first echo disappears from the screen, and then a second echo related to the longitudinal waves appears again and thus remains until the angle of incidence reaches the value of 13.56°. This angle of incidence is called the first critical angle of the longitudinal wave because it disappears from the examined specimen (Figure3).

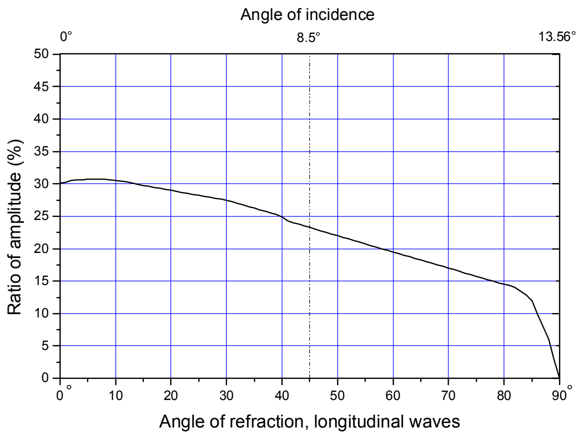

Figure3. Amplitude ratio between longitudinal waves and incident waves

If one continuous to increase the angle of incidence, and right after 13.56°, a stronger transverse wave appears and remains even with the increase in the acoustic pressure approximately 30° with 90° (figure4), whereas the angle of incidence reaches the value of 29.2°. This point is the second angle criticized and related to the transverse waves. Therefore, we are in front of the case of a longitudinal mode conversion towards the transverse mode, and the amplitude ratio reaches its maximum of 47% for an angle of incidence of 17°.

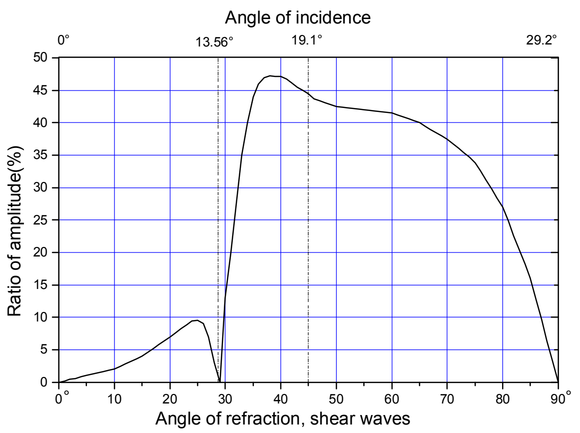

Figure4. Amplitude ratios between transverse waves and Incidental (second critical angle)

According to figure4, we can calculate two propagation velocities from formula (2.1). Speed is derived from the trajectory crossed at the time taken by the impulse to cross the interface separating the liquid and the sample.

$$c_{l,t} = \frac{a}{t_{l,t} - t_1} \quad \ldots\ldots\ldots\ldots\ldots \text{(2.1)}$$

3. Results and discussions

The shape of the echoes obtained through this experiment is shown on the figure5 until figure8. We obtained these curves there by handling the system thus carried out while making turn the support carries samples through an engine step by step, and while raising the graphs on the numerical oscilloscope.

In addition to aluminium, two other samples were used during this experiment. First is made out of brass with good cavity a size smaller than that of aluminium (has = 41millimetres). The second sample is made out of mortar with an average age of approximately 30 days when the tests were carried out and a size identical to that of aluminium.

With through the curves, one can note that the echoes raised on oscilloscope for the samples are quite clear by knowing that a frequency of the sensor of surroundings 2, 5 megahertz was employed during all measurements. It is what enabled us to evaluate times of transit in various samples with a good precision and an error of measurement on the propagation velocity of the waves bordering the 2%.

The exactitude of measurement is directly related to the base of time of the numerical oscilloscope. We used a base of times of 5 μ s/div. By gauging the base of time on 500 ns/div Figure8, we can reach an error which does not exceed the value of 2% on all speeds.

Two essential factors could influence the exactitude of measurement, consequently to increase where to decrease the error. The first is the regular rotation of the door sample. Therefore, to have a tiny error of measurement, it would be necessary to ensure the rotation of the support without any play.

The second factor making it possible to increase the exactitude of measurement is to take into account the preparation of the samples with a special care. By knowing that surfaces act directly on the final results, they should be reasonably punts.

Table1 shows the values of propagation velocities of the longitudinal waves and the transverse waves for the three examined samples.

In one deduces propagation velocities from the longitudinal and transverse waves C_l and C_t starting from the relation which expresses the report/ratio of the distance covered at the corresponding transit time.

$$C_{l,t} = \frac{a}{t_{l,t} - t_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

We can extract another relation much more significant and which depends only on the distance separating the transducer in the center from the principal face from the prism, that where speed is expressed as follows:

$$C_{l,t} = \frac{\sqrt{2}R(t_2 - t_1)}{t_1(t_{l,t} - t_1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

Where:

t_1: is the time of transit in water with normal incidence on the prism.

t_2: is the time of transit in water with normal incidence on the reflectors with in particular the absence of the prism.

$t_{l,t}$: is the time of transit in the presence of prism and the engine in rotation.

R: is the circle radius formed by the transducer around the sample.

	ρ (Kg/m³)	C_l (m/s)	C_t (m/s)
Aluminium (2017A)	2764	6380	3048
Brass	8782	4271	2127
Mortar	2006	3387	2072

Table1. Experimental values of propagation velocities

By comparing the values longitudinal and transverse speeds of the waves of reflexion and refraction for the three samples subjected to the tests, one notice which are very close theoretical speeds.

The same judgement can be related to the various second order elastic constants illustrated in table2.

This last includes propagation velocities for the two modes longitudinal and transverse, like all constant the rubber bands while starting with the constants of Lamé (λ and μ), then the Young modulus (E), then the module of Bulk (K) and finally the report/ratio of Poisson (σ).

According to the relations described in the first part bearing allusion to the elastic constants of the second order, one can express all these constants according to propagation velocities c_l and c_t.

Therefore, the Lamé's constants become as follows: *[4]*

$$\lambda=\rho\left(c_l^2-c_t^2\right) \qquad (2.3)$$

$$\mu=\rho c_t^2 \qquad (2.4)$$

The module of Bulk (K), that of Young (E) and the ratio of Poisson (σ) are expressed according to the two constants of Lamé (λ and μ):

$$k=\frac{3\lambda+\mu}{3} \qquad (2.5)$$

$$E=\frac{\mu(3\lambda+2\mu)}{\lambda+\mu} \qquad (2.6)$$

$$\sigma=\frac{\lambda}{2(\lambda+\mu)} \qquad (2.7)$$

If one replaces λ and μ with their values in the relations (2.5) until (2.7), one will obtain the three constants according to propagation velocities: *[5]*

$$k=\frac{\rho\left(3c_l^2-4c_t^2\right)}{3} \qquad (2.8)$$

$$E=\frac{\rho c_t^2\left(3c_l^2-4c_t^2\right)}{c_l^2-c_t^2} \qquad (2.9)$$

$$\sigma=\frac{c_l^2-2c_t^2}{2\left(c_l^2-c_t^2\right)} \qquad (2.10)$$

	ρ (Kg/m³)	c_l (m/s)	c_t (m/s)	λ (GPa)	μ (GPa)	E (GPa)	K (GPa)	σ (Gpa)
Aluminium (2017A)	2764	6380	3048	89	25.7	71.2	104	0.385
Brass	8782	4271	2127	120	38	109	147	0.376
Mortar	2006	3387	2072	14.4	22.6	22.6	20	0.31

Table1. Second order elastic constants (experimental values)

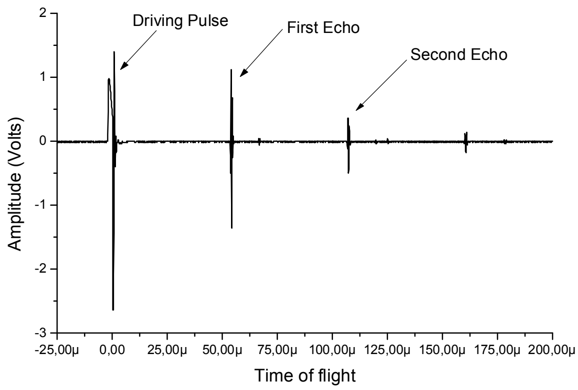

Figure5. Echoes reflected on the principal face of the prism (t_1)

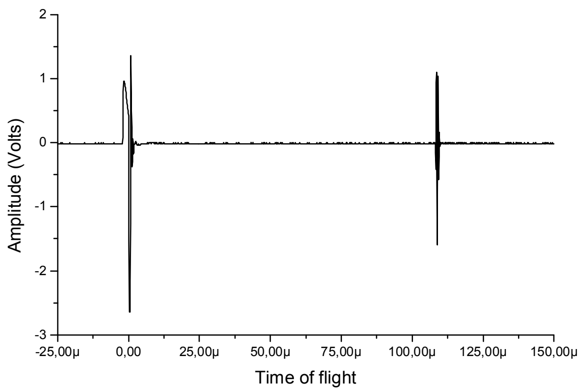

Figure6. Echo coming from the reflectors (t_2)

Times of transit t_l and t_t are illustrated through the two curves of figures7 and figure8. Figure7 on the other hand shows that the time of t_l transit of the longitudinal wave along the Aluminium prism is in the vicinity of 62.50 µS, the time of transit of the transverse wave t_t is of 72.50 µS as figure8 shows it.

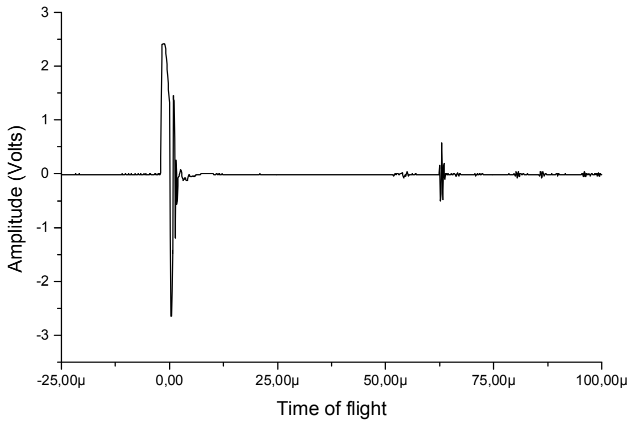

Figure7. Echo related to the longitudinal waves in Aluminium (t_l)

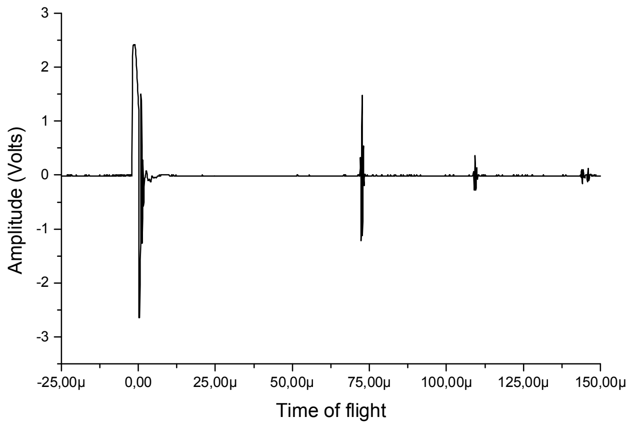

Figure8. Echo related to shear waves in Aluminium (t_l)

In the same way for the two other samples, we will obtain curves identical to those of Aluminium with different values, well cavity.

4. Echo-form

The figure 9 gives a quite clear idea on the real form of the impulse echo coming from the interface which separates the sample from the liquid ensuring the coupling; water for our case.

In order to determine the precise value of the echo, it is necessary well to adjust the cursor of curve's pointer to the position of the peak, E such kind that the amplitude of this last is maximum. The time of flight was measured by using a base of times of 5 µ s/div. This gave a definition of 0.2 µS for the cursors, and the error on the speed of the waves was in case approximately 2%.

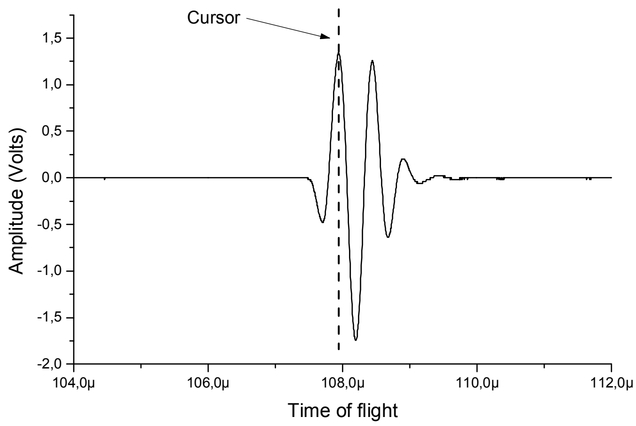

Figure9. Echoes Form

The base of time could be decreased up-to 500 ns/div; this gave an error only of 0.2% on the speed of the waves.

5. Conclusion

As the need to the non-destructive tests is accentuated, we harnessed ourselves to work out a slotted measuring section by ultrasounds to take into account the evaluation of the constant rubber bands of any material before even its use in industry.

By taking account of the major disadvantages that the traditional measurement techniques by means of the ultrasounds present, we could carry out a system of measurement simple in its design, and based on the principle of the pulsate-echo.

The use of this slotted measuring system opens many prospects. Initially, it would be very easy to introduce the phenomenon of anisotropy to the system by subjecting the samples to the external stresses generated by applying uniaxial and hydrostatic pressures on the specimen, which will widen its field of application, and to thereafter be able to calculate the third order elastic constants.

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